Improved Method for Measuring and Assessing Reticle Pinhole Defects for the 100nm Lithography Node

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ABSTRACT

With the approach of the 100nm-lithography node, an accurate and reliable method of measuring reticle pinhole defects becomes necessary to assess the capabilities of high-end reticle inspection equipment. The current measurement method of programmed defect pinholes consists of using a SEM. While this method is repeatable, it does not reliably represent the true nature of a pinhole.

Earlier studies have suggested that since the SEM images only a top down view of the pinhole, the measurement does not accurately account for edge wall angle and partial filling which both reduce pinhole transmission and subsequent printability. Since wafer lithography and reticle inspection tools use transmitted illumination, pinhole detection performance based on SEM measurements is often erroneous.

In this study, a pinhole test reticle was manufactured to further characterize the capabilities of a transmission method to measure pinholes.

Keywords: Inspection, Pinhole, Printability

1. PROBLEM DEFINITION

Because of the inability to reliably manufacture and measure programmed pinhole defects on test masks, some reticle inspection tool vendors have stopped setting a specification on these types of defects. This has left a hole in setting specifications from the customer of the mask houses.

From 1979 to the present, optical shearing microscopes were used to measure these defects. The resulting measurements were used in multiple printability studies in the industry. This method was adequate when the size of the defects were relatively large, however, issues began to arise when the defects fell below 500nm. The repeatability of the measurements became poor below 500nm and very poor below 200nm. In 2000 KLA-Tencor migrated to using a KLA-Tencor 8100XPR CD-SEM to measure the defects. This was done primarily for a high repeatability. The sizing method is the inscribed circle method. This involves placing a

circle inside the defect and reporting the size of the defect. This methodology was chosen due to the good correlation back to the historical optical sizing[1].

While SEM measurement are highly repeatable there are issues with this type of measurement. It cannot take into account poor sidewall or the presence of debris in the bottom of the pinhole. An example of this is shown in Image 1.

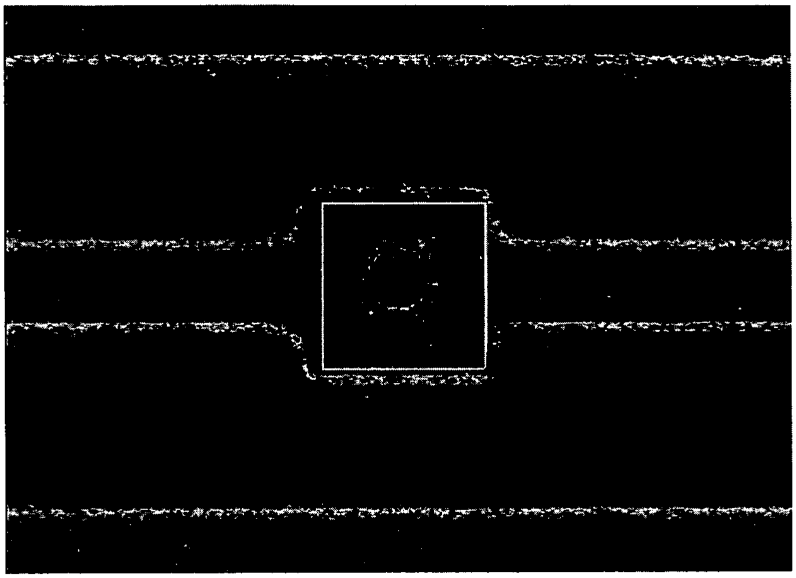


Image 1.
CD-SEM Circle Inscribed Methodology

The green circle is where the measurement was taken. As shown in the image there are very poor sidewalls on the defect. Image 2 shows an example of a "good" defect. This defect has a relatively high sidewall angle and is completely cleared.

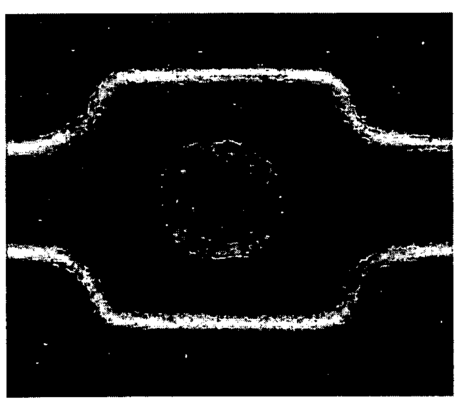


Image 2.
Example of a "good" pinhole

As the test mask geometry and defect sizes shrink it has become necessary to find a new measurement protocol to overcome the issues seen with the SEM measurements. Several methods were investigated such as probe type metrology, SEM improvements and transmission based metrology. There are issues associated with each of these. Probe type metrology is interesting but the size of the tip approaches or is larger than the defect of interest. SEM metrology could be improved to capture a better point in the sidewall, however, it does not address the issue of foreign material in the defect. Transmission based metrology appears to be the most comprehensive of the three and it more closely resembles the actual function of the mask in optical lithography.

Two transmission based measurement tools were investigated in this ongoing study of the issue, the KLA-Tencor Defect Energy Meter and the AVI™ Flux-Area Measurement tool. The KLA-Tencor DEM is an engineering mode tool that uses images from an SLF27 inspection tool to measure the defects. A special noncommercial extraction program was written that enabled the AVI tool to use the same images.. Both measurement techniques were shown to be repeatable within a single tool and from tool to tool in an earlier study on this problem[2].

The decision was made to use the AVI tool primarily because it has the ability to create a reference within the defect image and the KLA-Tencor DEM tool needs a separate reference image. KLA-Tencor has the ability to capture images of the defects manually on the SLF27, however, the reference image is not fully aligned which is necessary for the DEM to function.

2. EXPERIMENT

A programmed defect test mask based on the KLA-Tencor UTM was built using a 50KeV-lithography tool. The plate was designed for the 100nm node. The main feature size was 400nm and the defects were in increments of 20nm. The basis for the test plate was the KLA-Tencor UTM, this is the mask design that KLA-Tencor intends to use for setting the detection rate specifications on the 5XX generation tool.

This test mask was inspected multiple times on several KLA-Tencor SLF27 inspection tools and measurements made using the AVI tool on the individual runs. Chart 1 shows the repeatability of the AVI pinhole measurements from system to system. The X axis shows the average defect size measured with the AVI software while the X axis shows the variation from the average for each individual system. The data show less than ±3nm variation all the way down to the 116nm sized pinhole.

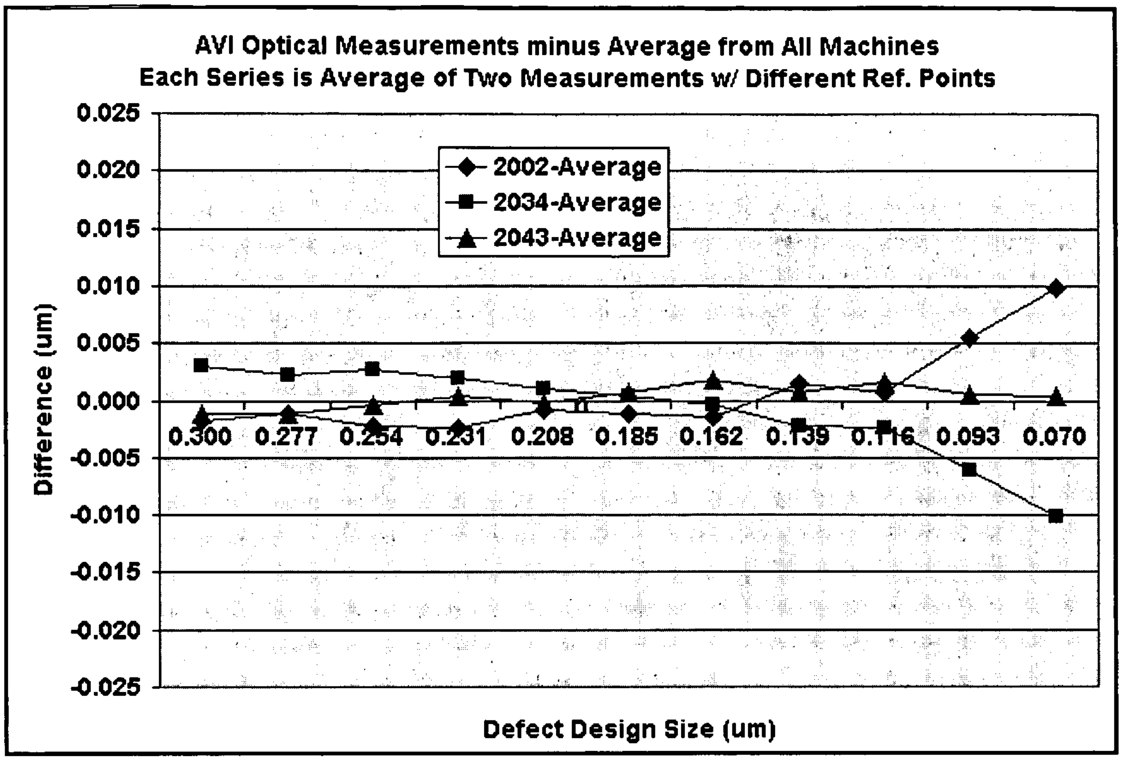


Chart 1.
AVI System to System Measurement Repeatability

Chart 2 shows the relationship between the AVI measured sizes and the CD-SEM sizes along with the delta between them. The delta has a range of 13nm. The yellow bar in the chart shows the 100% capture point for the SLF27 tool.

Defect #	1	2	3	4	5	6	7	8	9	10	11
SEM	425	400	382	360	337	317	294	270	252	228	206
AVI	300	277	254	231	208	185	162	139	116	93	70
delta	125	123	128	129	129	132	132	131	136	135	136

Chart 2.
SEM vs AVI measurements

Sensitivity measurements were taken from numerous inspection tools and the results from one system are shown in Chart 3. The gray area in the sensitivity chart represents 100% capture rate. The individual boxes show the actual capture rate for that particular defect. The average defect sizes as measured by the AVI are shown along the right side vertical axis

Sensitivity Table

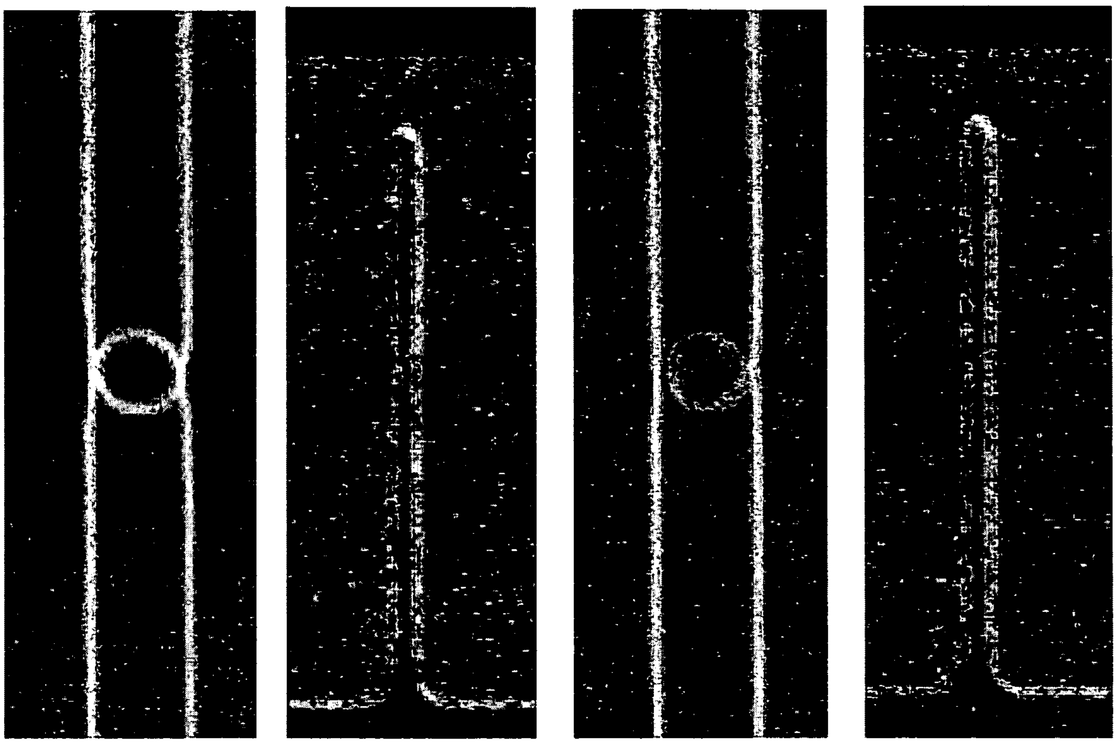
Surface: Chrome

1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	0.900 um x 0.900 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	
1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	0.900 um x 0.900 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	
1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	0.900 um x 0.900 um 0.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 0.00 %	
1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 10.00 %	1.050 um x 1.050 um 0.00 %	1.050 um x 1.050 um 80.00 %	1.050 um x 1.050 um 70.00 %	1.050 um x 1.050 um 10.00 %	1.050 um x 1.050 um 10.00 %	0.900 um x 0.900 um 60.00 %	1.050 um x 1.050 um 30.00 %	1.050 um x 1.050 um 60.00 %	.093
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.116
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.139
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.162
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.185
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.208
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.231
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.254
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.277
1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	0.900 um x 0.900 um 100.00 %	1.050 um x 1.050 um 100.00 %	1.050 um x 1.050 um 100.00 %	.300

Chart 3.
SLF Pinhole Sensitivity from Test Mask

3. PRINTABILITY

In earlier phases of this study printability was performed to get a sense of how transmission measurements compared to printability. A test mask designed for the 130nm node (520nm lines) was printed with aggressive low k_1 lithography (~ .42).



Defect 12 **Defect 12-wafer** **Defect 11** **Defect 11-wafer**

Images 3 through 6.
Printed Images for 130nm node

Images 3 through 6 show two consecutive defects on a programmed defect mask. There are two pair of images, one SEM image of the mask and the other is the SEM image of the printed wafer. The SEM circle inscribed method measurement on defect 12 was 215nm and the SEM measurement for defect 11 was 212nm. The AVI measurements for the same defects were 183nm and 114nm respectively. As shown in on the wafer images, defect 12 on the mask printed on the wafer causing the line to pinch. Defect 11 on the other hand did not print although the SEM measured only 3nm difference between them. The AVI measurement showed a difference of 69nm, which would be in better agreement with the printing results.

In the case of isolated pinholes the largest pinhole on the mask, which measured 279nm by SEM and 155nm by energy measurement, did not print.

The printability results suggest that the capture rate of the KLA-Tencor SLF27 tool is well below the printing threshold. The SLF captured the defects in the 116nm range 100% of the time. It also shows that the repeatability of the AVI tool is stable well below printing levels.

4. SUMMARY

Large strides have been made in overcoming the obstacles in repeatable measurement of small programmed pinhole reticle defects. The AVI transmission based measurement method chosen in this study showed good repeatability on very small defects far below what actually prints. The KLA-Tencor SLF27 system also demonstrated the ability to capture pinholes far below the printing threshold.

5. REFERENCES

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